Technical Evaluation Report

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SUMMARY

On 2-3 October 2006, the AVT-133 program committee of the Applied Vehicle Technology (AVT) Panel of NATO's Research and Technology Organization (RTO) held a Specialists' Meeting entitled "Fluid Dynamics of Personnel and Equipment Precision Delivery from Military Platforms" in Vilnius, Lithuania. The objectives of this meeting included reviewing the hierarchy of applicable simulation models, establishing the state-of-the-art in the Computational Fluid Dynamics (CFD) and ground test simulation of these types of operations, and making recommendations on ways to improve technical capabilities in these areas. All of the objectives of the AVT-133 Specialists' Meeting were met. Many key issues were discussed and some new innovative state-of-the-art computational and experimental research covered in the presentations made by the authors. A broad overview of numerous precision airdrop related applications was provided including a range of very basic research efforts, to near fully developed systems and qualification tests of fully developed systems, to existing fielded precision airdrop systems.

A follow on Specialists' Meeting is strongly suggested, perhaps within two years, to review the progress of work pursued in the area of fluid dynamics of personnel and equipment from military platforms and to determine how much validation in this area has been accomplished. The technical evaluator also makes suggestions in the recommendations section of this report regarding additional Specialists' Meetings related to precision airdrop for the RTO's consideration.

1.0 INTRODUCTION

1.1 Background

As noted in the meeting announcement, the rapid or cover projection of forces, or their logistic resupply, often involve operations in which personnel and/or materiel are dropped from airborne platforms. Typically, these operations require the delivery of palletized weapons from transport aircraft, the parachute extraction of heavy loads, and the ability to deploy a large number of paratroopers within a limited footprint. To ensure safety, payload and paratrooper collisions with the aircraft and other paratroopers must be avoided, and the potential for static line entanglements must be minimized during these operations. As a result, an identified military need exists to improve the precision with which these assets are delivered and to relax possible limitations on the transport aircraft with regard to altitude, speed, and configuration during the operation to reduce the threat to the crew and platform.

1.2 Theme

Accurate simulations of the initial stages of the dropped human/object's trajectory while moving embedded in the flow field induced by the delivering vehicle and possibly subjected to the loads introduced by an opening

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parachute in a non-uniform flow field are key elements to achieving the above described improved capabilities. These simulation tools potentially would allow for early identification of problems during the development phase, as well as the rapid mitigation of problems found during qualification tests. As a result, development costs and the time it takes to implement improved operational capabilities could be greatly reduced.

1.3 Objectives

The key objective of the specialists meeting was to determine the state of the art and on-going research activities related to fluid dynamics of personnel and equipment delivery from military platforms through in depth presentations and discussions among a variety of wide ranging specialists from researchers (theoreticians, numerical analysts and experimentalists) to aircraft designers, testers, systems developers, system integrators, program managers and military users from numerous services and backgrounds.

The main topics addressed were grouped into a Keynote session that provided an overview of UK, US, and NATO precision airdrop activities and the following four sessions:

- Industrial Experience/Engineering Methods
- Precision Delivery Systems
- Computational Fluid Dynamics
- Validation of Simulation Tools

Papers were solicited in the areas of precise simulation of the vehicle's wake flow, fluid dynamics modelling of unconventional bodies and 'soft structures," ground simulations such as wind/water tunnel tests and sled tests, rapid simulation using engineering methods and lower resolution models for on-board implementation, probabilistic approaches used to account for the inherent variability in deployment, and finally, the validation of simulation tools.

A total of seventeen contributions were selected for presentation at the Specialist Meeting. Unfortunately, four papers were completely withdrawn, and presentations were given, but no papers submitted, for Papers 6 and 7, respectively entitled: "Results of the NIAG Study on Precision Airdrop Technology", and "A400M Wake Flow Studies Based on RANS CFD Methods on Hybrid Meshes."

The seventeen selected contributions originated from ten different nations, most of them coming from industry and national or government agencies followed by a few from research laboratories and universities.

At its peak, upwards of thirty observers were counted in the audience of the most frequented session.

A summary of each paper that was presented at the meeting is provided in the following section, along with any live discussion, i.e., questions and answers, immediately following the presentation.

2.0 EVALUATIONS

2.1 Keynote Session

Paper K1: The United Kingdom's Air Drop Capability

This paper discusses the United Kingdom's present airdrop capability, as well as emerging trends likely to influence the country's thinking and possible procurement in the future. The paper begins by providing an

historical perspective of air despatch; from its origins during World War I, when the feasibility of supply from the air was first successfully demonstrated; its peak use during World War II, which coincided with the development of effective transport aircraft; as well as its post-war to present day use in military and civil contingencies, and high-profile humanitarian relief operations around the world. As a result, the UK has gained considerable experience in airdrop operations.

This is followed by a discussion of how the UK's requirements for airborne, and as a sub element, an airdrop or air despatch capability, are developed. A number of Strategic Defence Reviews, from the end of the Cold War to post 9/11, examined the UK's requirement for an airborne capability as part of theatre entry/rapid reaction forces. The conclusion was that the UK should retain an Airborne Task Force (ABTF) capable of being force packaged around a single battalion with associated combat support and logistics, as part of a Joint Rapid Reaction Force. Biennial direction provided by the Defence Strategic Guidance has led the Ministry of Defence to allocate resources to additionally retain the ability to deliver Special Forces and other specialist units, such as the brigade reconnaissance force of the Commando Brigade and Submarine Parachute Assistance Group, by parachute. Furthermore, a recently published Joint Warfare Publication envisions wider airdrop use beyond the support of airborne forces; including support to ground and maritime forces, and in UK disaster relief operations. As a result, a review of capabilities is ongoing to identify where capability gaps exist.

An overview of the UK's current airdrop capability is presented next. This capability is broken down into small stores ranging from 30 to 317 kg, medium stores ranging from 317 to 1000 kg, and large stores from 1000 to 8165 kg, consisting of heavy stores and equipment such as vehicles, light artillery, ammunition, fuel, and boats. Recent operations of the UK's Air Despatch Squadron are briefly reviewed and a number of lessons learned from these operations are presented with regard to concepts and doctrine, training, equipment, infrastructure, organization, personnel, interoperability, and logistics. Finally, emerging future trends influencing airdrop procurement, and the support role the Joint Air Transport Evaluation Unit plays at various stages in the acquisition cycle are discussed. Trends likely to influence future procurement include the need to acquire airdrop systems that provide greater operational flexibility by maximizing the aircraft's payload capacity, and the emphasis on high altitude precision airdrop. As a result, the UK is currently looking at alternatives to their Medium Stress Platform, which is only used by the UK and provides no options for interoperability with the equipment of allied/coalition forces. The Medium Stress Platform, which is becoming increasing expensive to support, would need to be modified to be dropped from the C-130J and A400M aircraft, and even then would not allow the user to maximize the aircrafts' payload capabilities. Similarly, work is ongoing in the UK to formalize a requirement for the precision delivery of cargo from altitude. Precision delivery discussions are focusing on whether the key requirements driver is to enable the insertion of forces or their subsequent re-supply; with current UK thinking leaning toward the former. It is expected that a mature requirement will be developed by late 2007.

It was concluded that the requirement to operate worldwide along with the need for greater precision, is driving the UK to rationalize its current capability.

Paper K2: NATO Precision Airdrop Initiatives and Modeling and Simulation Needs

This paper discusses the current status of the U.S. Department of Defense precision airdrop program, as well as recent activities of the NATO Joint Precision Airdrop Capabilities Working Group. The paper also highlights the need for precision airdrop and the airdrop community's Modeling and Simulation needs associated with the deployment of personnel and cargo from transport aircraft.

The paper begins with an overview of U.S. precision airdrop initiatives being carried out under a program, called the Joint Precision Airdrop System (JPADS) program. This program comprises four weight classes covering fully rigged loads weighing between 500 and 60,000 pounds. JPADS systems are expected to operate from altitudes between 25,000 and 35,000 feet Mean Sea Level (MSL), and have accuracies of 100 meters or better. All weight classes of the JPADS family of systems will use the U.S. Air Force's laptop computer-based JPADS Mission Planner to plan missions and program the units. This paper focuses on the first two JPADS weight categories; namely, JPADS-Light for 2,201- to 10,000-pound loads, and JPADS-Extra Light for 500- to 2,200-pound loads. These two categories are the most rapidly maturing, and are most needed by NATO nations. Therefore, the vast majority of NATO nations will likely field these systems. Within the JPADS-Light category, the status of an Advanced Concept Technology Demonstration (ACTD) that is currently being executed is discussed. Under this ACTD, the JPADS Mission Planner is being integrated with a modified High Altitude Low Opening (HALO) JPADS concept called "SCREAMER." The status of ongoing efforts to mature and prep a number of JPADS-Extra Light systems for interim fielding is discussed next. The JPADS-Extra Light systems that have or will be fielded as part of various Rapid Fielding Initiatives include the MMIST Sherpa, Strong Enterprises SCREAMER, and Capewell/Vertigo Affordable Guided Airdrop System (AGAS).

The paper next provides background on the NATO Joint Precision Airdrop Capabilities Working Group and discusses the group's recent activities. This group was formed in September 2004 to support the use of precision airdrop in military operations as one of ten high-priority requirements identified by the Conference of National Armaments Directors (CNAD) for the Defense Against Terrorism (DAT), as well as a Long Term Capability Requirement (LTCR) within NATO. The group is bringing Subject Matter Experts together to investigate the precision airdrop technologies that can be used to help define and meet the capability requirements to fulfil these needs. Specific activities discussed include the NATO group's assistance in the execution of international system airdrops at the 2005 Precision Airdrop Technology Conference and Demonstration (PATCAD), an ongoing Precision Airdrop Capability study, funded by the NATO Industrial Advisory Group, to assist NATO in meeting its needs, as well as the group's July 2006 execution of a Precision Airdrop Capabilities Demonstration (PACD) in southwest France.

Finally, the paper concludes with a discussion of the need for higher-order Fluid-Structure Interaction (FSI) simulation tools, as well as potential areas in which these tools might find application. This discussion begins by defining the FSI problem, and identifying modeling and airdrop phenomenology obstacles that will have to be overcome prior to their implementation. Specific application areas discussed include studying aircraft induced effects during personnel and cargo airdrop deployment, simulation of a precision airdrop system's canopy performance over its entire flight regime, and designing the retraction mechanism and determining the operational parameters of an active soft landing device.

It was concluded that there is a growing U.S. and NATO need for precision airdrop systems, as well as a need for higher-order FSI simulation tools to speed airdrop system development and reduce costs.

2.2 Session 1 – INDUSTRIAL EXPERIENCE/ENGINEERING METHODS

Paper 1: C-27J SPARTAN : Paratroops and Loads Airdrop Qualification

This paper provides an overview of flight test activities performed during the military certification of the C-27J tactical transport aircraft to airdrop personnel and various types of loads. The C-27J is a multi-role light-to-medium weight transport aircraft, developed as a joint venture between Alenia and Lockheed Martin. The aircraft is based on the Aeritalia G.222/C-27A airframe, and is specifically designed for rugged military

operations, including logistic support and tactical missions to unprepared remote airstrips, given its STOL capabilities. The C-27J is designed to perform cargo and troop transport, loads airdrop including LAPES, high and low altitude paratroop airdrop, and medevac and aerial surveillance, in all weather and without need of ground support.

The flight test program was conducted by Alenia with support provided by the Italian Army, the Italian Air Force, civilian paratroopers, and contractor personnel from Capewell and AAR. The program's objectives were to demonstrate the aircraft's ability to safely airdrop paratroopers from the side and cargo doors, as well as loads from the cargo door, achieve military qualification of the C-27J to airdrop paratroopers and loads according to the System Specification targets, demonstrate a considerable expansion in airdrop capabilities over those of the G222 aircraft, assess the CARP mechanism's performance, and supply the customer a fully qualified operational system.

Flight test activities discussed in the paper include the flight test instrumentation used, the preliminary steps taken to minimize risks, including airflow investigations and dummy testing, as well as the specific personnel and cargo airdrop tests performed to certify the aircraft. Personnel airdrop qualification tests included more than 200 paratrooper static line jumps and 20 using the free fall technique. They included single jumps or multiple jumps conducted simultaneously or in sequence from one or both of the C-27J aircraft's side doors or the cargo door. Jumping conditions, in terms of airflow and ability to manoeuvre just outside the C-27J aircraft when using the free fall technique, were judged to be far better than those of the G222 aircraft. A trajectory analysis of sequential jumping further showed positive results with regard to the risk of intersection and collision.

Cargo airdrop qualification tests were carried out in four distinct phases. In the first phase, single and multiple A-22 loads weighing between 500 and 1000 kg were successfully airdropped either in a single release or in sequence using the gravity technique. In the second phase, medium to heavy loads rigged on 8 ft to 12 ft Type V platforms were airdropped using the extraction technique. Platform loads airdropped during this phase weighed between 2500 and 6000 kg, and were extracted using 15 ft or 22 ft extractor parachutes. Tests of single and multiple platform loads were successfully conducted, demonstrating the C-27J's ability to airdrop the maximum single load of 6000 kg and the maximum 9000 kg payload. The tow-plate was new to the C-27J, never having been used with the G222 aircraft. Therefore, in the third phase, LAPES experiments were conducted to test the aircraft's flight qualities and to gather data on trim conditions and power settings to be used when airdropping loads using the tow-plate technique. These tests provided a lead-in to the fourth phase, in which single platforms weighing 2500 and 5000 kg, and two linked platforms, each weighing 2500 kg, were successfully airdropped using the LAPES technique. In cargo offload tests, the C-27J aircraft also performed well; being ready to take off immediately after completing release of payloads weighing up to 6000 kg.

As a result, the C-27J aircraft has been fully qualified for the airdrop of personnel and cargo; demonstrating safe characteristics and very good CARP precision. Furthermore, the flight test program has demonstrated the C-27J aircraft's ability to airdrop twelve more paratroopers and eighty percent more load than the G.222 aircraft. The aircraft's handling qualities during airdrop, compared to the G.222, are also improved due to its new flight control system.

Paper 2: Experimental and Computational Modeling of Parachutes Fluid Dynamics

This paper provides a brief overview of experimental and computational parachute research being conducted at the Central Aerohydrodinamic Institute (TsAGI) in Russia. The paper begins with a description of two

subsonic wind tunnels, which are being used to conduct experimental research on large-scale models over a broad range of parameters. The wind tunnels are both continuous return-flow type facilities with open test sections for testing various objects including parachutes, paragliders, etc. The larger wind tunnel's test section measures 24 meters in length with an elliptical nozzle measuring 14×24 meters. The smaller facility's test section is 13 meters in length and 7 meters in diameter, and is capable of investigating unsteady aerodynamic effects on parachutes.

A description of numerical models and methods currently in use is provided next. These include the method of discrete vortices for investigating the flow nearby an airplane along with the near and far wake parameters. This method, along with experimental verification, provides a quick, reliable means of examining various flow parameters, and can be used to describe the flow in the vicinity of an opening parachute in the near wake of an aircraft. Other numerical models, described in the paper as full Euler models, are then briefly reviewed and references provided for the benefit of readers interested in obtaining more information.

A comparison between computational and wind tunnel results obtained for the pressure coefficient distributions on the AN-124 aircraft's wing surface is presented next. The goal of this effort was to analyze the influence of small-scale elements, such as pylons and engine cells, on the flow field and wake structure. Generally, subcritical flow regimes show good correlation, with supercritical flow regimes showing some difference, especially in the vicinity of shock waves. An examination of results showed small-scale turbulence to have insignificant effect on the structure, size, and position of the vortex core and other parameters. Although the main focus of this effort was to describe the vortical flow behind the aircraft, the method can also be applied to modelling of the near wake as well.

Finally, a series of plots showing the flow field in the vicinity of a parachute and the parachute's geometry as a function of time are presented. The plots are based on numerical modelling results obtained for a parachute in uniform subsonic flow. From these studies, it was concluded that special computational techniques based on geometrically and dynamically adaptive meshes are needed to model parachutes.

Paper 3: Computer Simulation of Paratrooper Deployment by Static Line from A400M

This paper reports on the development of a computer simulation capable of predicting the static line deployment of a paratrooper from the A400M aircraft. The objective is to develop a theoretical model capable of identifying potential airdrop problems early on during the development stage, when design modifications are comparatively easy, quick, and inexpensive to implement. Traditionally, type-specific rules and procedures for paratrooper deployments from military transport aircraft have been determined during flight testing, once all airworthiness, control and handling issues have been sorted out. Problems, which surface during flight testing, however, often require complex and expensive fixes, as demonstrated in the case of the C-17 aircraft. Simulations such as this are needed to analyze the risk of "crossover;" a potentially lethal condition where paratroopers are drawn toward the centreline behind an aircraft, resulting in paratrooper collision and/or parachute entanglement.

A detailed description of the methods used to model the deployment process, from the moment the paratrooper exits the aircraft to full canopy inflation and beyond, is presented. Basically, the deployment process is split into three phases, which are modelled using different theoretical approaches. Straightforward Newtonian trajectory integration is used to simulate the first jump phase, which begins when the paratrooper exits the aircraft and ends when the static line is stretched. A finite element approach is used to simulate the bowing of the parachute under the aerodynamic loads, which occurs during extraction from the deployment bag. Finally, canopy inflation is modelled using the semi-empirical Pflanz-Ludtke method.

Deployment within the non-uniform flow field around the A400M aircraft is modelled using a combination of data from wind tunnel tests for the near field and CFD calculations on the aircraft for the far field. Therefore, the methodology takes into account the effects of the flow field on the paratrooper, but does not, conversely, take into account the effect of the paratrooper on the flow field. As a result, runtime is significantly less than that required for a full CFD computation of both the aircraft and paratrooper.

The ability to perform Montecarlo simulations of the trajectories from the mean and standard deviation values of various parameters was designed into the computer program, allowing different probability distributions for each parameter, given the uncertainties in their values. Montecarlo studies can be carried out for either a single parameter or for a set of parameters, allowing one to study the resultant effects on the range of movement. A series of plots showing results for each phase of the deployment sequence, as well as Montecarlo simulation results for the paratrooper mass parameter, is presented in the paper. These initial results show close agreement between the predicted and actual shapes of the trajectory, when compared with photographs and video taken of actual paratrooper deployments. However, a further and more thorough validation of the results is required. Once flight testing of the A400M aircraft gets underway and specific airdrop tests are carried out, data gathered will be used to fine tune the simulation to improve the quality of predictions.

2.3 Session 2 – PRECISION DELIVERY SYSTEMS

Paper 4: IoA Experience on Aerial Delivery

This paper reports on recent research conducted by the Institute of Aviation (IoA), Warsaw to develop a simple, inexpensive precision aerial delivery system, called “SkyMule”, consisting of an unmanned parafoil and payload weighing up to 200 kg that can be controlled either autonomously or remotely by a human operator. The aim of this research is to design and construct an automatic trajectory controller for the unmanned parafoil and payload system to make it useful for precise aerial delivery tasks.

The “SkyMule’s” payload is composed of two connected but separate modules: the control module and the cargo module. The control module contains the electronic and electro-mechanical components including the servo-actuators, the PC-104 based control computer, the measuring unit, and a set of 12V batteries. The cargo module can be of varying dimensions and shape. The measuring unit contains a GPS receiver, MEMS-type gyroscope, MEMS-type pressure sensors, and electronic compass, and is designed to provide feedback signals for automatic control. The PC-104 computer is provided with software for pre-programming the site of destination and flight trajectory. Modelling the system’s flight dynamics is not only a difficult and complex task, but also expensive, given the number of experiments needed to obtain satisfactory results. Therefore, considerable efforts are being focused on the development of robust control algorithms that will ensure directional stability, even for large variations in the size and shape of the cargo module. The measuring unit and the control computer have been flight tested using both a small UAV and the PRP-560 “Ranger” patrol and rescue hovercraft, which was designed and manufactured at the institute. Results of tests conducted to date have been satisfactory and encouraging.

The “SkyMule’s” motion is controlled by two control cords operated by the electro-mechanical servo-actuators. The servo-actuators are provided with DC motors and are controlled by a current regulator based on Pulse-Width Modulation (PWM) of the voltage. The motion of the motor’s shaft is converted into a linear displacement of the control cord by means of an intermeshing rack gear and rack belt, similar to an automobile’s rack-and-pinion steering mechanisms. A picture of the actuator mechanism is presented along with laboratory test results depicting actual verses desired rack belt position resulting from manual excitation of the actuator. Excellent correlation is obtained with the resultant control errors being very small.

Flight testing of the control module, which measures 300×280×180mm and weighs 15kg, is scheduled to begin in late autumn 2006. These tests are expected to yield both new and alternative ideas for predictive or adaptive control system modifications, as well as insights into dynamic refinements that need to be made to the system. The “SkyMule” project’s future is greatly dependent upon generating interest from potential purchasers in need of an inexpensive precision aerial delivery system. The institute is therefore actively looking for both military and civilian partners both in Poland and abroad to help fund further development.

Paper 5: Precision Airdrop System SPADES

This paper reports on the further development of the Smart Parafoil Autonomous Delivery System (SPADES) in order to give this precision cargo delivery system the ability to deliver 100 to 1000 kg payloads using different ram air parachutes for different weight classes. SPADES was developed by Dutch Space, in partnership with the National Aerospace Laboratory (NLR) in The Netherlands. The complete SPADES precision airdrop unit is composed of three main parts; parafoil, Aerial Guidance Unit (AGU) or control-unit, and payload container. The AGU, which controls the parafoil in flight, contains the on-board instrumentation and computer running the Guidance, Naviagation, and Control (GN&C) software. The system uses Global Positioning System (GPS) information to fly autonomously toward a delivery point. During mission planning, rough wind information, as used in para jumps, is used to estimate the air-volume in which the Calculated Air Release Point (CARP) can be selected. The system itself does not require any information on the wind profile. The system assesses the wind profile on-board during flight. Therefore, the coordinates of the desired impact point is the only pre-flight information that needs to be input into the guidance system in order to execute a mission.

The first SPADES developed and demonstrated was a 160 kg version based on the G9-Galaxy ram air parachute. Recently, in an effort to further extend the system’s payload capacity, developmental flight tests have been conducted using a PBO tandem-parafoil to deliver up to 250 kg, and Para-flite’s Firefly parafoil, which is suitable for payloads between 500 and 1000 kg. As a result, experience has been gained with using various types of parafoils capable of delivering payloads over the entire 100 to 1000 kg range. Flight testing of suspended weights between 90 and 500 kg has demonstrated the system’s ability to deliver payloads to programmed ground locations with an accuracy of better than 100 meters (CEP). Currently, a new control-unit is being designed for the delivery of payloads over the entire 100 to 1000 kg weight range. Incorporating lessons learned during the development phase, as well as general user requirements, a modular design approach has been adopted for the new control-unit, making it user-friendly in terms of operation and handling. The new unit consists of two parts: control box with instrumentation, and a structural frame for transfer of the forces from the parafoil to the payload. Each part will weigh a maximum of 25 kg, so that the unit can easily be retrieved upon landing. The new control unit will be available by the end of 2006.

An in depth discussion of the performance features of the new operational SPADES configuration is provided in the paper, with regard to maximum drop altitude, accuracy, stand-off capability, flared soft landing ability, and meteorological conditions in which the SPADES can operate. The system can be dropped from altitudes in excess of 30,000 ft; with the control-unit having been designed for atmospheric conditions up to 35,000 ft. Additionally, an example of wind information used to determine the CARP is presented, and the SPADES wind velocity measured in-flight by the processor based on sensor information is compared and shown to be similar with data obtained from two PADS-dropsondes.

Based on this effort, it was concluded that the new SPADES will use three types of ram air parachutes to respectively cover the payload ranges of 100 to 250 kg, 250 to 500 kg, and 500 to 1000 kg. It was further concluded that the new operational SPADES will be able to fulfil the short term precision airdrop requirements of the international defence forces.

Paper 6: Precision Airdrop for Special Operations: NATO Industrial Advisory Group (NIAG) Study Group 94

No paper was submitted for review but the presentation was provided and attempts will be made to include the paper on the RTO website.

The NIAF SG94 objectives included the development of a technology roadmaps and cost reduction recommendations for Precision Airdrop systems, components and related technologies.

The presentation showed results related to the following objectives:

- Development of a comprehensive Technology Roadmap and assist in the prioritization of technologies needed with the JPACWG. Explore and make recommendations on how to promote more Government-Industry and Industry-Industry cooperation regarding PAD.
- Recommend methods/investments that can help reduce PAD system costs?
- What are industries projected costs of PAD systems and technology/development needs and what are the driving largest costs/breakdowns? In what component/complimentary technologies should Nation's invest now for long term PAD needs? Moreover explore and recommend future technology investments.

2.4 Session 3 – COMPUTATIONAL FLUID DYNAMICS

Paper 7: A400M Wake Flow Studies Based on RANS CFD Methods on Hybrid Meshes

At the time this report was being prepared, a paper for this topic still had not been received for review, although a presentation was given and received at the Specialist Meeting. Computational results of wake flow studies conducted on the A400M aircraft with the paratroop doors and cargo ramp both closed and open were presented. Flight conditions examined typically included an altitude of 500m, speed of Ma=0.2, angle of attack of 0 degrees, and Re equal to 25×10^6. A half model of the aircraft without the empennage system was examined. This model consisted of 8.4/8.96 million grid points.

The Hybrid RANS solver TAU used in these studies is characterized as follows:

- Finite Volume, vertex-based with edge-based data structure
- Various element types, dual-grid technique
- Default settings: central differencing scheme, Runge-Kutta time integration, multi-grid acceleration
- Turbulence model: SA with Edwards modification

A number of approaches to improve the accuracy of predictions were reported on, including matrix dissipation, vortical flow correction, and low Mach number preconditioning. Although these first results seem plausible and consistent, it was concluded that further improvements are possible. Therfore, work is continuing in this area. Also, there is no test data currently available to validate the simulation.

Paper 9: Store Separation Modelling Strategies Applied to Military Transport Aircraft

This paper presents examples in which store separation modelling strategies based on advanced CFD methodologies have been applied to the delivery of a paratrooper from the side door and an unmanned air

vehicle (UAV) from the cargo bay of a military transport aircraft. The models have demonstrated their reliability across the complete flight regime including subsonic, transonic, and supersonic speeds; having their origins in advanced fighter aircraft design, development, and integration work to address store separation issues arising from military operational requirements. The algorithms being used are Euler based finite volume schemes with more or less universal capabilities to handle structured or unstructured messes. The specific examples presented use an H^3 structured scheme, in combination with a Chimera Type superposition of several meshes; the scheme currently favoured by EADS store separation experts.

A brief overview of store separation modelling strategies being used at EADS is first presented. These modelling strategies encompass both Pseudo Dynamic Strategies and Time Dependent Solution techniques. Pseudo Dynamic Strategies consist of a number of single static solutions that are sequentially produced using traditional methods for solving the aerodynamic interference effects for store release and jettison problems. They include the Decay Factorisation, Flow Angularity, and Iterative Methods. Time Dependent Solutions, necessary for the determination of theoretical high fidelity store trajectories, are split into two main solution approaches: Global Re/Meshing Solutions and Dynamically Overlapping Grids (DOG). In the Global Re/Meshing Solution scheme, the aircraft and stores are modelled within a single mesh of structured, unstructured, or hybrid type grids. For each store position, the grid is changed or built up again. In the DOG solution scheme, however, the aircraft and store meshes are modelled separately, and the store is positioned within the aircraft grid as necessary depending on the trajectory computation, in accordance with the chimera principle.

The specific CFD methodologies employed in modelling the interactions of the paratrooper and UAV respectively with the aircraft are discussed next and results of the simulations presented. Paratrooper deployment methodologies discussed include a description of the predictor-corrector scheme used to estimate the aerodynamic forces and moments acting on the paratrooper in order to increase the accuracy of the trajectory and minimize the computational effort. Paratrooper simulation results presented include plots showing the surface pressure distributions on the aircraft and paratrooper, and global time histories of the paratrooper’s motion. Aerostructure or UAV deployment methodologies discussed include the data set evaluation and sectioning strategy employed, as well as modelling of the constraints and parachute retard force. Aerostructure simulation results presented include plots of the UAV’s longitudinal, vertical, and pitch motion for various sized extraction parachutes, UAV pitch angle when gravity dropped at various aircraft angles of attack, as well as a comparison of a flight test movie of a cargo delivery with a computed trajectory.

Based on the promising results obtained, it was concluded that properly designed store separation codes are well suited to solving problems associated with transport aircraft personnel and cargo deployments. The use of high fidelity CFD methods offers attractive and efficient solutions for all kinds of payloads or complex interference situations, including those involving personnel. In combination with Chimer Schemes, solutions to problems involving unsteady flow are even possible.

2.5 Session 4 – VALIDATION OF SIMULATION TOOLS

Paper 10: Capabilities of Deployment Tests at DNW-NWB

This paper reports on store separation tests conducted in the open test section of the low speed wind tunnel NWB, which is operated by the foundation German-Dutch Wind Tunnels (DNW). In these tests, store deployments were simulated using rigid objects (cubes) jettisoned from the open ramp of a generic model of a military transport aircraft. The purpose of these tests is to gather data on store separation characteristics in order to generate a data base for the validation of CFD simulations. This data base, which will be generated in

stages, will eventually include data on the flow field in close vicinity to the open ramp, surface pressure measurements, force measurements, and measurement of the trajectories and orientation of the deployed objects. Results presented here are for the first wind tunnel tests, which were performed to measure the trajectories and orientation of the deployed objects.

The paper begins by providing technical background on the wind tunnel NWB facility, as well as the unique test setup developed and equipment used to conduct the tests. A detailed description is provided of the NWB's unique 6-Degree of Freedom (DoF) model positioning mechanism (MPM), the generic military transport aircraft model equipped with a store ejection mechanism tested, as well as the optical tracking, and data acquisition and evaluation systems used to determine the trajectories of the rigid bodies. The NWB is an atmospheric wind tunnel with a closed return circuit that can be operated either with a closed, slotted or open test section. For the present tests, the open test section was chosen due to its better optical access, even though there is a reduction in flow quality compared to the closed test section. The military transport model, which has a wing span of 2 meters, was equipped with an open cargo ramp. The deployed cubes were 110 mm (4.3 inches) long, 90 mm (3.5 inches) wide, and 50 mm (2 inches) high. The cubes, which were made from three different density materials, respectively weighed 60, 290, and 500 grams, and were deployed from the cargo bay at a speed of 1 meter- per-second in all tests.

Photos taken during tests using the low, medium, and high density cubes, along with select plots of test results, are presented and discussed next. Plots shown include medium density cube trajectory results for repeatability tests, and tests conducted at angles of attack between 0 and 6 degrees, as well as high density cube trajectory results for tests conducted at free stream velocities between 16 and 20 meters-per-second. Trajectory photos show the medium and high density cubes leave the vicinity of the rear fuselage immediately and without rotation about the cube's longitudinal axis. However, the low density cube, which is strongly influenced by the low static pressure region and the vortex dominated flow past the lower side of the rear fuselage, initially moves upward and rotates about all three body axes. Repeatability tests conducted using the medium density cube show great similarity in the x and z directions, but considerable variation in the y direction, resulting from the unsteadiness of the flow past the lower rear fuselage. This trend is also observed in the plots of results conducted at different angles of attack and free stream velocities, but to a lesser extent for the high density cube.

As a result, it was concluded that the vortex dominated flow field in the vicinity of the open ramp significantly influences the repeatability with respect to the lateral displacement. This inherent unsteadiness will have to be addressed in future tests.

Paper 11: Experimental and Computational Results of a Simplified C-130 Shape Depicting Airflow Influence on Airdrop

This paper reports on work conducted as part of the Airflow Influence on Airdrop (AIA) project, which is an international project involving the US, UK, France, and Germany, that started in July 2002. The project's goal is to develop a better understanding of airdrop issues while validating state-of-the-art computational fluid dynamics (CFD) methods to predict the aerodynamic loads and the flow pattern around the C-130 Hercules aircraft. The overall project is comprised of wind tunnel tests, CFD simulations, and flight tests of a full scale C-130. This paper documents results of the second phase of this project, including wind tunnel and companion CFD simulation results for a simplified C-130 with an accurate aft portion that includes the horizontal tail as well as the rear door in both closed and open configurations.

The wind tunnel experiments were conducted by the French team of ENSICA and included determination of the lift and drag forces as a function of incidence as well as Particle Image Velocimetry (PIV) flow

visualization to better understand the relevant aerodynamics in airdrop activities. PIV is a whole-flow-field technique that provides instantaneous velocity vector measurements in a cross-section of a flow non-intrusively. The method is based on the velocity measuring of sub micron-sized passive seeding particles, fast enough to perfectly follow flow fluctuations up to hundreds of kHz, resolving most of the turbulence scales.

The numerical simulations, performed by the United States Air Force Academy, incorporated the use of Reynolds Averaged Navier-Stokes (RANS) methods for steady-state simulations and the promising Detached Eddy Simulation (DES) method for unsteady simulations. The DES method now being used at the Air Force Academy and many other locations for flow field prediction is considered the best simulation tool available for capturing the flow field in the wake of the aircraft where the flow is massively separated. Other turbulence models, such as Large Eddy Simulation (LES) and RANS are very universal and are not adaptable to massively separated flows. The DES method takes advantage of both approaches; benefiting from the fine-tuned RANS technology in the attached boundary layer and the good prediction of LES in the separated regions.

Some basic post-processing issues dealing with convergence criteria and averaging are first discussed in the paper. Next, a comparison between CFD and wind tunnel results is presented for lift and drag coefficients at different angles of attack, and for the flow field in the aircraft's wake with the cargo door in both the closed and opened configurations. Based on a comparison of RANS and DES results, it was concluded that the RANS method seems to predict the aerodynamic coefficients as well as DES for the same baseline grid and that the RANS method is fairly efficient at predicting the mean loads for this case. However, the RANS method is too dissipative to accurately predict the separated flow in the up-sweep region. The cost of DES can be avoided it the aerodynamic coefficients are the only goal, but to predict separated flow, DES should be applied. DES numerical results showed very close agreement when compared to PIV measurements taken in the wind tunnel. Furthermore, a study of 2D flow fields in the wake of the aircraft showed that DES was able to very accurately predict the birth of the up-sweep vortex, as well as the interaction between the up-sweep vortex and the horizontal tail or the interaction between the up-sweep vortex and the detached vortex.

As a result of these very promising results demonstrating the potential of DES simulations to predict the flow around a simplified C-130 Hercules, new grids have already been created for DES simulations that match the clean, cargo door open, and side door open flight conditions. The next step in the AIA project will be the comparison of flight test data to DES simulations.

Paper 12: Validation of a Gliding Parachute Simulation Model through System Identification

This paper describes the development of a mathematical model of a parafoil system using the system identification method. System identification is a powerful method for the validation of mathematical models from experimental data. For validation of the gliding parachute system model, flight test data was collected using a 100 kg experimental parafoil test vehicle developed by the Institute of Flight Systems of the German Aerospace Center (DLR). The test vehicle is called ALEX, which is an acronym for Small Autonomous parafoil Landing Experiment.

The paper begins with a description of the ALEX parafoil-load system and the flight test instrumentation package carried onboard to gather data. Flight test instrumentation consisted of GPS, inertial and airdata sensors, magnetometer, actuator position transducers, and a video camera looking toward the canopy to capture the relative motion between the parafoil and load. A total of twenty-four flight tests were conducted with the vehicle dropped from altitudes ranging from 600 to 2000 meters above the ground. The mathematical model used to simulate the physics of the parafoil-load system is next described. For simplicity, the entire

parafoil-load system is treated as a rigid body with six degrees of freedom (DoF). This model was considered adequate for describing the nominal flight behaviour when flexibility of the canopy and suspension system is negligible. Equations for the dimensionless aerodynamic force and moment coefficients are presented, along with nonlinear deflection terms used to account for flexibility and deformations of the textile canopy in the model equations.

Application of the system identification method, using the acquired flight test data to determine the aerodynamic characteristics of the ALEX system, is described in detail and results presented. The process begins with the so-called flight path reconstruction in order to identify scaling factors and offsets for the measurements. This step also permits determination of the local wind profile for the corresponding flight test. A detailed discussion of the video analyzing techniques used to determine the relative motion between the canopy and load is presented along with a time history plot of the payload motion, relative motion, and corrected canopy motion. Estimation of the aerodynamic parameters and application of the Maximum-Likelihood identification approach is discussed next. Using this approach, longitudinal and lateral flight dynamics are analyzed both together and separately in order to obtain the best match between simulated and measured time histories, yielding the most likely parameters set for the system model. For validation, the quality and reliability of the identified parameters are evaluated according to their standard deviation, correlation with other parameters, and the match of the corresponding simulated and measured time histories. In addition, trim computations are performed and the identified model is linearized and compared with the theoretical assumptions in the frequency domain. A plot showing the correlation obtained between simulated and measured ALEX motion after system identification is presented.

As a result, it was concluded that the system identification method represents a viable technique for validating mathematical models of parafoil-load systems. Due to the limited accuracy of the low-cost sensors used, a good deal of effort went into flight path reconstruction in order to compensate for the relative motion in the data. However, very plausible, reliable aerodynamic coefficients were obtained for the parafoil canopy using the processed data. Furthermore, by comparing differences between the original theoretical and identified models, one can ascertain in which direction the model should be extended or changed to match reality.

3.0 CONCLUSIONS

The Air Vehicle Technology (AVT) 133 specialist meeting provided all participants an excellent overview of numerous precision airdrop activities; that although were often unrelated, nonetheless, were of interest to all participants.

Numerous Nations, industries and universities participated in the sessions. Many papers focused on the primary specialist meeting focus “Fluid Dynamics of Personnel and Equipment Precision Delivery from Military Platforms” with modelling and experimental attempts to insight and predictions to this complex problem with many applications. Computational modelling work primarily based on Computational Fluid Dynamic (CFD) codes with a focus on specific flow volumes critical to exit locations on the vehicle and a number of novel approaches which couple the CFD to a rigid or flexible body/payload were shown. On the experimental side, the specialists saw significant value in using the experimental results for insight into these challenging problems and for the useful data obtained for model validation. The need, in some cases, for modelling activities to be more closely linked to experimental efforts was deemed valuable by the majority of participants.

The meeting provided an excellent overview of the state-of-the-art in modelling, wind tunnel experiments and full scale testing of the intended topic area. In addition, a variety of existing National and or industry precision

airdrop systems were reviewed and a number of other applications and efforts that will benefit from the tools being developed were presented.

Modellers and experimentalists are generating realistic results and early validation between model and scaled experimental results are showing very close correlation. The utility of the modelling capability and scaled experiments to influence the design of military transport platforms is still a few years away from reality due to the time lines involved. However, the capabilities of the tools being developed and refined now are at a state which can and should be used to assist in and/or influence system development programs involving deployment of personnel and equipment from military platforms.

From the discussions in the final technical wrap up session, the specialists all found the meeting beneficial and agreed that future meetings on this and other precision airdrop related topics would be valuable to all NATO Nations.

4.0 RECOMMENDATIONS

A wide range of recommendations are offered below based on discussions with all participants and authors after the final session paper.

- The Specialist meeting was very successful and useful to the participants and most agreed that a follow on specialist meeting in this area within 2 years would be beneficial to all.
- Computational modelling of this challenging problem has progressed significantly over the past few years and early validation of results against scaled experimental data on specific flow field are showing excellent correlation. The group encouraged the modelling and experimental participants to seek out each other for collaboration and validation between current and future experimental results and modelling capabilities. It was discussed that this is difficult at times due to proprietary data (for instance on the geometry of the aircraft) but all agreed that seeking opportunities would be beneficial to this research and technology area.
- Many other areas of research that are on-going and/or needed to meet the Long Term Capability Requirement on “Precise Delivery of Equipment and Supplies by Air Drop” (LTCR MF06-4 - AC/224-N(2004)0002) were discussed in the final session. Most were not related to this primary topic of the specialist meeting but the specialists agreed that listing them for future RTO consideration was warranted in this TER. Below are the topics
  - **Low cost automated parachute manufacturing**: Parachute manufacturing is most often conducted by an enormous amount of touch labor (hand sewn systems). The ability to automate the manufacturing process would allow for significant cost reductions in systems. Some manufacturers are beginning this process with laser cutting tables but the sewing process is generally still done by hand and very labor intensive and specialized.
  - **Low cost height sensors**: Most self guided precision airdrop systems rely on GPS as their primary sensor. However, GPS is not accurate enough in the vertical results to conduct near ground accurate flare manoeuvres or final softlanding retraction applications. Low cost height sensors that can detect vegetation, see through smoke/fog and not be spoofed by approaching a canopy from above at altitude are needed.
  - **Low cost fwd looking wind sensors**: Precision airdrop system accuracy improvements could be greatly enhanced with the addition of a forward looking wind sensor which was directly linked to

the onboard guidance navigation and control (GN&C) system. Accurate knowledge of near ground winds for a final approach to the pre-planned landing coordinates will drastically improve the accurate placement of these show moving airdrop systems.

- **Low cost GN&C systems (INS)**: As stated, the primary sensor used in commercial-off-the-shelf precision airdrop systems is GPS. Many scenarios for resupply of warfighters could be in GPS denied environments due to either jamming or terrain features (mountains, buildings etc.). The introduction of an inertial navigation system, a back up beacon approach capability or other sensors, perhaps leveraged from other systems/programs is envisioned to be very helpful for precision airdrop. Other methods of navigation sensors research for precision airdrop applications are needed.
- **Stealthy systems**: It has been seen through NATO sponsored Precision Airdrop Capability Demonstrations (PACD) and other events that precision airdrop systems (personnel and equipment) are quite visible by a variety of detection systems that many of our advisories have. The ability to employ stealth technologies to the airdrop system (canopy, suspension lines, payload/paratrooper" would had great value to precision airdrop systems and provide the warfighter with a significantly greater element of surprise.
- **Acoustics models within PAD Mission planners**: A slight tangent but of significant value is for precision airdrop mission planning would be the ability to utilize forecast and/or in-situ weather information with detailed terrain data-bases to determine the acoustic footprint of the delivery vehicle to help ensure that advanced detection through acoustic observers on the ground is minimized.
- **High-end weather sensors**: Airdrop based forward and downward looking weather sensors are needed. Weather/wind information allows the military aircraft to maximize the release offset from a planned target while also having significant value when fed to a precision airdrop GN&C system for optimizing a flight path and accurately hitting the ground. Wind errors are the most significant error source for high altitude ballistic systems. Future research in the area of onboard aircraft forward and downward looking weather sensors usable in all weather is needed.
- **Others**: The NATO Industrial Advisory Group (NIAG) Study Group 94 final report also lists a wide range of research and technologies (short, medium and long term) that would support the LTCR for precision airdrop. The group agreed that a review and National prioritization of the NIAG study group work would be beneficial and help identify the most cost effective technologies to invest in.